Hybrid Dynamic Pricing Model for Transport PPP Projects during the Residual Concession Period

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Abstract: Public-Private-Partnerships (PPPs) have been adopted worldwide to deliver infrastructure projects and/ or provide public services. Having a reasonable concession price (operation and transfer) in place is pivotal for sustaining a win-win relationship between governments and private sectors. However, historical data have shown that the concession price of PPPs when transfer is less than satisfactory due to the changing attribute of pricing parameters, causing substantial loss of residual value (RV). Nevertheless, a rational and systematic pricing model for PPPs, especially transport PPPs is yet available. To this end, a hybrid dynamic pricing model for transport PPPs during the residual concession period underpinned by the Case-based Reasoning technique is proposed. Furthermore, using a case study of Western Harbor Crossing tunnel in Hong Kong, the proposed model is validated to be able to account for the dynamic pricing parameters and calculate a reasonable and accurate residual concession price. The contributions of this study are twofold: (1) it highlights that a

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reasonable concession price beyond the operation period is significant in maintaining RV; (2) it provides a hybrid dynamic pricing model for governments and private sectors to calibrate the current less-than-satisfactory residual concession price.

Keywords**:** Case-based Reasoning; PPPs; Residual concession price; Residual value; Transport infrastructure.

Introduction

Public-Private Partnerships (PPPs) have been adopted worldwide to deliver infrastructure and/ or provide public services (Cheng et al. 2016; De Los Ríos-Carmenado et al. 2016). In a typical PPP project, the private sector is authorized to finance, design, build and operate the project, and transfer the asset to the host government after the concession period expires. Such an arrangement is expected to ease governments' fiscal constraints and provide quality services (Kwak et al. 2009; Bulsara et al. 2015; Ameyaw et al. 2015). However, the asset early terminated/ transferred usually cannot meet the output specifications set in the concession agreement, imposing adverse impacts on governments' subsequent management and thus triggering the loss of residual value (RV) (Yuan et al. 2018). For example, the Nanjing Yangtze River Tunnel was returned to the local government due to the standoff in the toll level negotiation. The consequence of this early transfer is the huge loss of RV for both contractual parties (Yuan et al. 2016). With lots of PPPs being at or about to enter the transfer stage (Tassopoulos et al. 2014), their RV continues to suffer and will remain so unless obstacles in the pricing mechanism are tackled.

Although RV can be affected by a number of variables (Burke and Demirag 2015; Yuan et al.

2015), Yuan et al. (2015) has identified that profitability is a critical factor that influences RV. In addition, profitability is determined by the concession price of PPPs, which indicates that a reasonable concession price has a positive impact on RV (Shen et al. 2007; Xu et al. 2012). This is supported by the fact that governments and private investors tend to negotiate a price that can secure a rational return and guarantee the successful implementation of PPPs concurrently. As such, considerable studies have been conducted on pricing mechanism (Liu et al. 2017; Hassan et al. 2013), pricing methods (e.g. game theory, cloud computing data) (Bonnafous 2010; Bai and Li 2017), and price adjustment mechanism (Chen 2013; Liu et al. 2017). For instance, Xu et al. (2012) proposed a model to determine the concession price for PPP highway projects using system dynamics. Moving ahead, Wang et al. (2018) considered the impact of not only price but demands and the concession period on shaping an optimal build-operate-transfer (BOT) contract under government subsidies. Nevertheless, most of these studies focus on product pricing in the concession period and therefore have a tendency to be static. Contrastingly, the pricing of PPPs is a rather complicated and risky process containing various influencing parameters (Chen and Nozick 2016). Owing to their changing attributes, the price when asset is transferred to the government is usually undesirable (i.e. too high or too low). However, few studies have been undertaken to investigate PPP concession pricing from the perspective of these dynamic parameters, especially during the residual concession period.

To fill this gap, this study aims to address the following research question: “How can a dynamic concession price be determined in transport PPPs during the residual concession period?” Acknowledging that the varying trend of these parameters affecting the concession price can be depicted through similar projects, Case-based Reasoning (CBR) approach is used to acquire knowledge on residual concession price determination (Bu et al. 2018; Yuan et al. 2018). Specifically, determination of concession price during the residual concession period comprises: (1) constructing the concession pricing model at the end of the concession period through Cost Benefit Analysis (CBA); (2) applying CBR to accommodate the changing trend of price parameters and proposing a hybrid dynamic residual concession model; (3) testing the developed model using a real-world transport PPP project.

The reminder of this paper is organized as follows. It begins by providing a comprehensive overview and analysis of literature focusing on pricing of PPPs and CBR. The research approach then introduces the overall research framework. In the following section, the hybrid dynamic model including model formation and model adjustment is detailed. The case study section verifies the proposed model using the Hong Kong West Harbor Crossing (WHC) tunnel project. This paper finishes with a concluding remark on its contributions.

Literature Review

Pricing of PPP Projects

According to World Bank (2017), there is not a universally accepted definition of PPPs and their contract types vary. Nevertheless, some common characteristics have materialized over their decades of development, including large-scale investment (e.g. millions of dollars), long-term contracts (e.g. 30 years or more) and multiple project stakeholders (e.g. the government, the private sector and the general public) (Wang et al. 2018). Similarly, risks are undoubtedly embedded within the life cycle of PPPs, such as financing risk, poor public decision-making process, completion risk, and inability of concessionaires (Iyer and Sagheer 2010; Carbonara et al. 2015; Burke and Demirag 2017). Inadequate management of these risks could result in unsatisfactory performance or even project failure. In order to mitigate these risks and ensure project success, many studies have been conducted on risk-oriented decision methods (Grimsey and Lewis 2002; Ke et al. 2010), procurement methods (Lam and Chow 1999; Kumaraswamy and Morris 2002), concession-related issues (Shen and Wu 2005; Ng et al. 2007), economic problems (Chang and Chen 2001; Xenidis and Angelides 2005), and success factors for PPP projects (Li et al. 2005; Zhang 2005). Of note, concession related issues have formed a significant research field, in which concession period and concession price play a major role (Cui et al. 2008).

PPP product pricing is a complicated and rather risky decision-making process and has to maintain a balance between different stakeholders (e.g. the private sector, the public sector and the general public) (Bai and Li 2017). In order to win the bid, it is necessary for private investors to cast a low concession price. As they are profit-driving, they also prefer a high concession price to guarantee the rate of return. In comparison, governments aim for a concession price that does not exceed the budget and can sustain the operation of PPPs. The general public concerns about whether the adjustment of prices is affordable on the premise that the same level of service is provided. Inherent variances of stakeholders' interests are not the scope of this paper, but the uncertainty they bring to the pricing of PPPs should be noted. In line with the uncertainties (e.g. financial risk and revenue risks), they render the pricing of PPPs to be dynamic in nature. In other words, if they are not treated in the process, the concession price when transferred back to the government will be either too high or too low, causing enormous loss of the RV (Li et al. 2005). By and large, such uncertain issues as market risks and project risks have been overlooked in the current methods (see next section), jeopardizing their ability in dynamic adjustment of concession price.

Pricing of Transport PPPs

Infrastructure pricing is an important topic in PPPs as it determines the commercial variability and profitability of a project (Tassopoulos and Theodoropoulos 2014; Kweun et al. 2018). A rational price during the residual concession period, therefore, can contribute to the accumulation of RV by satisfying both contractual parties (Tassopoulos and Theodoropoulos 2014). Accordingly, there is an abundance of literature that has studied infrastructure pricing, particularly in the field of transport (see for example, Shen et al. 2007; Bonnafous 2010; Xu et al. 2012; Chen 2013; Hassan et al. 2013; Liu et al. 2017; Bai and Li 2017). Among them, marginal cost pricing mostly applies to government-funded projects while the capital asset pricing model (Yuan et al. 2018), game theory model (Dai and Song 2010), a system dynamics pricing model of PPP expressway projects (Liu et al. 2017), and multi-objective planning (Burke and Demirag 2015) focus on PPP projects. Despite the different applications, these models unanimously place emphases on the pricing mechanism and pricing adjustment of transport projects (Claire et al. 2019). However, the existing models pervade in the concession period without a consideration of 'what the price will look like' during the residual concession period, which determines RV after transfer. For instance, although Bonnafous (2010) considered the impact of unexpected changes on projects' price, it neglects pricing parameters during the residual concession period.

What is more, in spite of the identification of various uncertain factors that affect transport PPPs

(Yu, 2006), they have rarely been integrated into pricing models, particularly during the residual concession period. For example, Xu et al. (2012) argue that the quantifiable operation cost should be taken into account when calculating transport PPPs' toll. In another case, government support should be captured as transport PPPs' toll can be lowered because of the government subsidy. The unaccountability of both qualitative and quantitative parameters in current models disabled their ability in the dynamic adjustment of concession price. Put simply, they tend to be static by nature. Therefore, it is imperative to have a dynamic pricing model in place to embrace large numbers of PPPs that are entering the residual concession period.

Case-based Reasoning (CBR)

It has been acknowledged that CBR can solve the problems of the target (new) case with similar situations of previous cases (Aamodt and Plaza 1994). Specifically, the core of CBR is remembering past situations and reusing their solutions to the new case through four procedures: (1) Retrieve; (2) Reuse; (3) Revise; and (4) Retain (Aamodt and Plaza 1994). Retrieve is a search process in which the most relevant cases are located in the case database by calculating the local similarity and global similarity between the selected case and the target case. Then, the solution of the similar cases is initially applied to the new case scenario at the Reuse stage. Furthermore, Revise process adjusts the past solutions to fit the new situation. In Retain process, the derived solution of the new problem is stored as a new case (Cho et al. 2017).

As one of the emerging paradigms for designing intelligent systems, CBR is robust in improving the effectiveness of complex and unstructured decision-making. Essentially, CBR has been widely implemented to address decision-making issues regarding finance (Lei et al. 2001; Seo et al. 2007), medical diagnosis (Li and Yeh 2004), and knowledge management (Ahn et al. 2007) to name a few. Noteworthy, CBR is the most common method used to develop decision support systems in the field of construction engineering (Lee et al. 2019). Many applications have been found in risk management, knowledge management, building maintenance, and green building simulation with forecasting and monitoring being the primary focus (Cheng et al. 2009). For instance, Wang et al. (2003) build a technology integration knowledge repository using the CBR approach. The CBR system can not only reflect an objective condition of past PPP projects with stored historical data but can also provide an objective method for retrieving similar experience with the similarity algorithms (Lee et al. 2019). Moreover, data stored in CBR system can be revised and updated, ensuring a comprehensive and live case database. Thus, all-sides of experiences are available for solving problems of the new case. More importantly, attributing to the embedded artificial intelligence, CBR approach is more efficient and effective than manpower (Yuan et al. 2018). As a consequence, decision makers, such as governments and PPP project operators, can obtain desired advice and experience (e.g. changing trends of uncertain parameters) through CBR’s user-friendly interface.

Pricing of PPPs, a forecasting and monitoring process, is undertaken mostly using methods identified above, which are arguably compatible with PPPs’ pricing as they are rule-based (Liu et al. 2017). It means that these pricing mechanisms exist without scientific rules due to the lack of theoretical foundations and changing parameters. In contrast, CBR is based upon shallow knowledge and does not require significant efforts in knowledge engineering (Bu et al. 2018). This creates an ideal environment for the adoption of CBR in PPPs’ pricing as it relieves the burden of lengthy analysis of the problem domain and improve efficiency and quality of PPPs' pricing (Feng et al. 2006). Nevertheless, there is a lack of studies efficiently applying CBR to the pricing of transport PPPs and proposing a novel residual pricing model that accommodates their changing features during the residual concession period. Relying on an accessible database of historical PPP projects, this study represents one of the first in using CBR to dynamically address PPPs' concession price during the residual concession period.

Research Approach

A hybrid approach combining CBA and CBR is adopted to address the dynamic pricing parameters in transport PPPs. CBA is the most common pricing method used in the project feasibility analysis to offer an initial price (Thomas and Chindarkar 2019). Given the changing attribute of pricing parameters, CBR, as above mentioned is well suited to develop a hybrid pricing model during the residual concession period drawing on experience of past similar cases (Aamodt and Plaza 1994). Without considering the rich experience and information obtained from past cases, the changing trend of pricing parameters remains ambiguous. Therefore, CBR enables a comprehensive understanding of 'what will look like' in the target project based on what has transpired in the past (Weick et al. 2005). By doing so, this research contributes to the body of knowledge by proposing a hybrid dynamic pricing model for transport PPPs during the residual concession period. The research framework is presented as Figure 1.

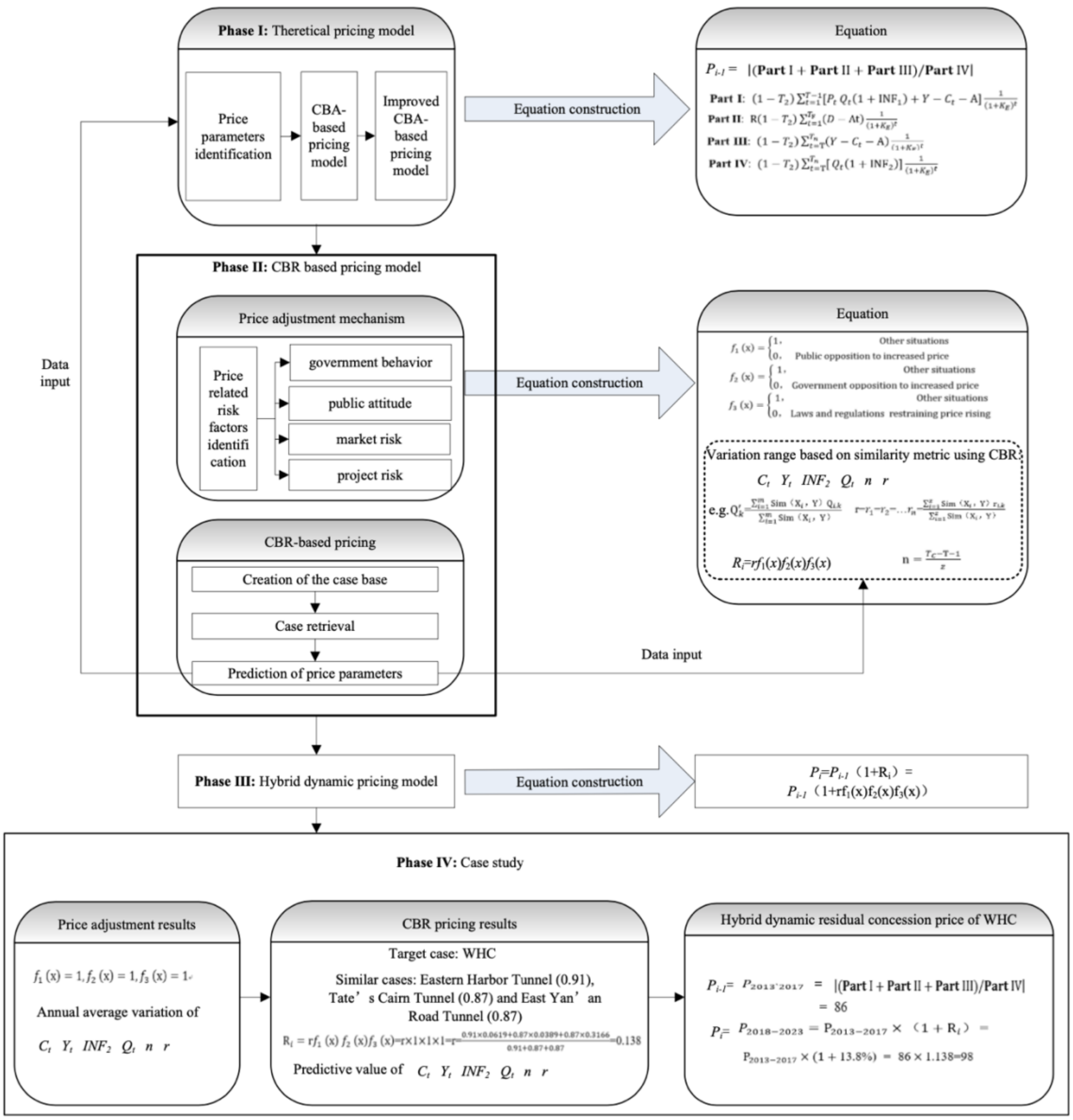

Figure 1. Research framework

- Phase I, theoretical pricing model (P_{i-1}). First, parameters affecting the residual concession price are identified to construct the theoretical pricing model that is based on CBA. Second, in order to overcome the deficiencies in CBA, an improved pricing model is developed.
- Phase II, CBR based pricing model (R_i). First, a dynamic price adjustment mechanism is

proposed by considering four categories of uncertainties (i.e. changing risk factors), which incorporate: (1) government behavior; (2) public attitude; (3) market risk; and (4) project risk. Second, CBR is employed to provide data input for the price adjustment mechanism and the theoretical pricing model. Specifically, the most similar case is retrieved from the case database through calculating their local similarity and global similarity. In order to calculate the global similarity, the weight of attribute i can be acquired using the expert evaluation method through a questionnaire survey, which has proven to be effective in PPP related research (Xenidis and Angelides 2005). Then, price parameters, including changing features of the pricing parameters and the price adjustment range (i.e. r) are predicted using the most similar case.

- Phase III, hybrid dynamic residual pricing model (P_i). First, the residual concession period and the periodicity of the concession price are calculated. Second, the final hybrid model is proposed according to the equation $P_i = P_{i-1}(1+R_i)$.
- Phase IV, case study. The WHC tunnel in Hong Kong is selected as the target case to test the model proposed in Phase III. In the case, the Eastern Harbor Tunnel (EHT) is identified as the most similar case from a case database containing 41 past transport projects, based on which values of the changing risk factors, such as traffic volume (Q_t), exchange rate (e), inflation rate (INF_2), operation cost (C_t), other revenue (Y_t), price adjustment range (r) and price adjustment period (n) are predicted by employing CBR. The result is then discussed.

Hybrid Dynamic Pricing Model

Theoretical Pricing Model

CBA-based pricing model for transport PPPs

The concession price of transport PPPs is usually negotiated and confirmed after the project feasibility study, in which an initial price is proposed using a CBA. A CBA begins with compiling a comprehensive list of all the costs and benefits associated with the project or decision, namely cash outflow parameters and cash inflow parameters (Tassopoulos and Theodoropoulos 2014). Subsequently, the CBA result is generated either by subtracting costs from benefits (Eq. (1)) or by dividing benefits by costs (Eq. (4)). As the concession price forms part of the cash inflow parameters, its value (P_t) can be calculated by transforming the equations.

The cash outflow side (i.e. expenditure) consists of cost and tax, in which project cost (i.e. total construction cost and operation cost) determines the concession price level (Tassopoulos et al. 2014). The total construction cost comprises material cost, labor cost, equipment cost, price reserve fund, and construction period loan interest. As private sectors are responsible for constructing the project, it is obvious that an appropriate concession price will help them reimburse this part of cost (Huang et al., 2004). Therefore, the total construction cost has a close relationship with the PPP project cost and concession pricing. The operation cost refers to the daily expenses incurred in running a PPP project, such as sales and administration fees. Transport PPPs feature a long-term operation up to 50 years and require corresponding maintenance funds, the amount of which is largely related to the operation entity's management standard, technology standard, and personnel competency (Li and Yeh 2004). By contrast, the cash inflow side (i.e. revenue) is surrounded with traffic volume, concession period, and the concession price (Ng et al. 2007b). The concession period defines the time span in which the concessionaire has the right to construct, operate, and maintain the project until it is transferred to the government (Tassopoulos and Theodoropoulos 2014). Concession price is the source of revenue during transport PPPs' concession period, which is commensurate with market conditions and government policies. An accurate forecast and determination of the concession price at the transfer stage based on reliable data and inference processes can assist stakeholders in accumulating RV.

Having considered the pricing parameters in both sides, the result of the aggregate costs and benefits should be compared quantitatively to determine if the benefits outweigh the costs. Thus, based on the cash outflow and inflow parameters, the theoretical transport PPPs' concession price is formulated in Eq. (1).

$$B_t - C_t = [(P_t \cdot Q_t + Y_t) \cdot (1 - T_1) - C_{kt} - e_t \cdot R_t \cdot D_t - C_d] \cdot (1 - T_2) + C_d - e_t \cdot \mathrm{A} \quad (1)$$

$$P_t = P \cdot (1 + INF)^t \quad (2)$$

where $B_t - C_t$ means the net profit in year *t*, P_t is the concession price in year *t*, Q_t is the traffic volume in year *t*, Y_t is the other revenue in year *t*, T_1 is the sales tax rate, C_{kt} is the operation cost in year *t*, e_t is the exchange rate in year *t*, R_t is the interest in year *t*, D_t is the loan in year *t*, C_d is the depreciation, T_2 is the income tax rate, *A* is the annual principal repayment, *P* is the initial price, and *INF* is the annual rate of inflation. Notably, the same annotations apply for the following equations.

In order to facilitate the calculation, it is assumed that (1) during the operation stage, exchange rate, interest, other revenue and operation cost remain the same, thus e_t=e, R_t=R, Y_t=Y, C_{kt}=C_k, where *e*, *R*, *Y* and C are the initial exchange, interest, other revenue and cost, respectively; (2) project loan in year 0 is D and the principal is repaid equally every year during the operation/ concession period, thus D_t=D-A • t. In addition, depreciation is calculated using the average life method. In this case, the net profit during the concession year can be represented as:

$$\sum_{t=1}^{T_c-T_0}(B_t - C_t) = \sum_{t=1}^{T_c-T_0}\{\left[\left(P \cdot Q_t\ (1+INF)^{t} + Y\right) \cdot (1-T_1) - C_k - e \cdot R \cdot\ (D - A \cdot t) - C_d\right] \cdot\ (1-T_2) + C_d - e \cdot A\} \quad (3)$$

According to CBA, a benefit-cost ratio (BCR) can be computed to summarize the overall relationship between the costs and benefits of a proposed project. If the BCR is no less than 1, the project is economically feasible. Therefore, with the constraint shown in Eq. (4) and input of other parameters, the initial CBA-based pricing model is constructed.

$$BCR = \frac{B}{C} = \frac{\sum_{t=1}^{T_c-T_0}\ (B_t - C_t)\ (1+K_E)^{-t}}{C_0} = 1 \quad (4)$$

where T_c is the concession period (i.e. unit: year), T_0 is the construction period (i.e. unit: year), C_0 is the total construction cost and K_E is the discount rate.

Improved CBA-based pricing model for transport PPPs

Given that the CBA-based pricing model in Eq. (3) is characterized with incomprehensive pricing parameters, unchanged annual operation cost, single inflation rate and a lack of residual value risks, following improvements have been made:

- The influence of government behavior, market risk, project risk, and public attitude on the concession price are explained in the improved model, which will be discussed in the next section;
- Data at the current research time and after are predicted based on the historical data of operation period, which reflects a dynamic attribute, such as the different operation cost (C_t)

each year;

- The influence of force majeure, project quality, service quality, depreciation (C_d) and operational accident on project pricing are adjusted into the operation cost;
- The single inflation rate is divided into the average inflation rate in the past concession stage (INF_1) and the simulated average inflation rate from current research period to the residual concession period (INF_2). In addition, the sales tax rate (T_1) is assumed to be zero due to the unavailability of the data of sales tax rate. For consistency purpose, foreign currency loans for project investment have been converted into local currency, which means exchange rate (e) is set to be 1.

In brief, C_k and C_d in Eq. (3) can both be included in C_t, and T_1 is 0 and e is 1. Therefore, Eq. (3) can be rewritten as Eq. (5).

$$\sum_{t=1}^{T_c-T_0} B_t - C_t = \sum_{t=1}^{T-1}\left[P\cdot Q_t\,(1+INF_1)^{t} + Y - C_t - A\right]\cdot(1-T_2) + \sum_{t=T}^{T_c}\left[P\cdot Q_t\,(1+INF_2)^{t} + Y - C_t - A\right]\cdot(1-T_2) - R(1-T_2)\cdot\sum_{t=1}^{T_{\mathrm{F}}}(D - A\cdot t) \quad (5)$$

By integrating Eq. (4) (i.e. $\sum_{t=1}^{T_c-T_0}(B_t - C_t)(1+K_E)^{-t} = C_0$) into Eq. (5), the improved CBA-based pricing model is as follows:

$$(1-T_2)\left\{\sum_{t=1}^{T-1}[P\,Q_t(1+INF_1)+Y-C_t-\mathrm{A}]\frac{1}{(1+K_E)^t}+\sum_{t=\mathrm{T}}^{T_c}[P\,Q_t(1+INF_2)+Y-C_t-\mathrm{A}]\frac{1}{(1+K_E)^t}\right\}-\mathrm{R}(1-T_2)\sum_{t=1}^{T_{\mathrm{F}}}(D-\mathrm{A}t)\frac{1}{(1+K_E)^t}=C_0 \quad (6)$$

where T_{F} is the payment deadline agreed in the contract and T is the current research period.

The improved CBA-based pricing model (i.e. Eq. (6)) is then transformed to Eq. (7) to facilitate the calculation of the theoretical concession price.

$$(1-T_2)\sum_{t=1}^{T-1}[P_t\,Q_t(1+INF_1)+Y-C_t-\mathrm{A}]\frac{1}{(1+K_E)^t}-\mathrm{R}(1-T_2)\sum_{t=1}^{T_\mathrm{F}}(D-\mathrm{At})\frac{1}{(1+K_E)^t}-C_0+(1-T_2)\sum_{t=\mathrm{T}}^{T_c}(Y-C_t-\mathrm{A})\frac{1}{(1+K_E)^t}=-(1-T_2)\sum_{t=\mathrm{T}}^{T_c}[P_tQ_t(1+INF_2)]\frac{1}{(1+K_E)^t} \quad (7)$$

As it is a polynomial equation with high order, each term of Eq. (7) is analyzed.

Part I: $(1-T_2)\sum_{t=1}^{T-1}[P_t\,Q_t(1+INF_1)+Y-C_t-\mathrm{A}]\frac{1}{(1+K_E)^t}$ refers to the present value of after-tax profit before the current study year.

Part II: $\mathrm{R}(1-T_2)\sum_{t=1}^{T_\mathrm{F}}(D-\mathrm{At})\frac{1}{(1+K_E)^t}$ refers to the present value of interest in the payment deadline.

Part III: $(1-T_2)\sum_{t=\mathrm{T}}^{T_c}(Y-C_t-\mathrm{A})\frac{1}{(1+K_E)^t}$ refers to the present value of after-tax revenue after current study year.

Part IV: $(1-T_2)\sum_{t=\mathrm{T}}^{T_c}[\,Q_t(1+INF_2)]\frac{1}{(1+K_E)^t}$ refers to the present value of after-tax traffic volume after current study year.

Therefore, the theoretical pricing model can be finalized as:

$$P_{i-1}=\left|\frac{\text{the present value of net profits over the concession year}}{\text{the present value of traffic flow after current year}}\right|=|(\textbf{Part I}+\textbf{Part II}+\textbf{Part III})/\textbf{Part IV}| \quad (8)$$

As shown in Eq. (8), the theoretical pricing model can provide the government and the private sector with an initial concession price. However, as previously mentioned, there are uncertainties (i.e. both quantifiable and unquantifiable risk factors) dramatically impacting transport projects' residual concession price. Thus, a price adjustment mechanism that takes into account the impact of risk factors should be put in place to yield the "win-win" dynamic pricing model.

CBR-based Pricing Model

Price adjustment mechanism

Due to the long-term construction and operation cycles of PPPs and affiliated risks, the actual concession price of transport PPPs usually deviates from the estimated value (i.e. the initial concession price). For example, inflation can bring currency depreciation and a decrease in the investor's actual return. Hence, there is no doubt that the investor will require an increase to the concession price to compensate for the inflation loss. In order to address these risks and ensure a dynamic concession price, pertinent risk factors need to be identified. Risks in PPP projects have been studied and categorized by many researchers (e.g. Chan et al. 2015; Xenidis and Angelides 2005; Chou et al. 2012). In this study, drawing upon the authors' prior studies (Yuan et al. 2018), verified price-related risk factors in transport PPPs are listed in Table 1.

Table 1. Price-related risk factors in PPP projects

Category	**Risk factors**	**Description**	**References**
Government behavior	Authoritative Intervention	Excessive administrative intervention or ineffective supervision	(Xenidis and Angelides 2005; Yang 2011; Cho et al. 2017;)
	Policy and legislation change	Local government's inconsistent application of new laws and regulations, such as changes in land management law, taxation law, labor law, environmental law, etc.	
Public attitude	Public attitude	The general public's reaction to the increase of price	
Market risk	Demand	An increase in market demand (traffic volume)	
	Interest rate	The uncertainty in interest variation owing to immature local economic and banking systems	
	Foreign exchange	Fluctuation in currency exchange rate and/or difficulty in convertibility	
	Inflation rate	The rise in the overall price and the decrease in the market value or the purchasing power of the currency	
	Peer competition	The bidding competition and possible quotations from the rivals	
	Construction quality	The project quality may fail to reach its expected standards and result in high	

		construction cost and low production efficiency
	Service quality	The project quality may fail to reach its expected standards and result in high construction cost and low production efficiency
Project risk	Unforeseen weather and geotechnical conditions	force majeure
	Construction cost	Cost overrun
	Operation cost	Cost overrun
	Construction period	Schedule delay
	Concession period	Schedule delay

Based on the retrieved risk factors that impact the concession price, following price adjustment is proposed to mitigate the loss of RV after project transfer.

Adjustment coefficient based on government behavior and public attitude

Quasi-public goods, the intermediate between public goods and private goods, are featured with imperfect competition and externality (Yu 2006). Transport PPPs are such products as their prices are dominated by both the government and the market (Shen and Wu, 2005). The administrative intervention usually takes effect when the market fails. For example, if the rising price is supported by the government or laws and regulations, then the price would rise. Alternatively, the price would remain unchanged. What is more, it is proved that the general public's attitude is critical towards the concession price of PPP projects (Hodge et al. 2017). Specifically, in the case of public protests or choosing an alternative service due to the rise of concession price, measures would be taken by the government or the market to adjust the price (Ho et al. 2015). In this sense, the general public plays a fundamental role in determining the price adjustment. The impact of these risks on the concession price can, therefore, be expressed by a 0-1 function as follows:

$$f_1(x) = \begin{cases} 1, & \text{Other situations} \\ 0, & \text{Public opposition to increased price} \end{cases} \tag{9}$$

$$f_2(x) = \begin{cases} 1, & \text{Other situations} \\ 0, & \text{Government opposition to increased price} \end{cases} \tag{10}$$

$$f_3(x) = \begin{cases} 1, & \text{Other situations} \\ 0, & \text{Laws and regulations restraining price rising} \end{cases} \tag{11}$$

'Other situations' in $f_1(x), f_2(x), f_3(x)$ can be scenarios whereby: (1) when prices of PPP projects go up, the reactions of the public, government, and laws and regulations are supportive; (2) the price remains unchanged; and (3) the price falls. It means that when 'other situations' hold, the value of function representing the effects of these three factors is 1.

Adjustment coefficient based on market risk

The influence of peer competition in market risk on project pricing is reflected in traffic volume. Thus, quantifiable factors related to market risk, including traffic volume, exchange rate and inflation rate, are discussed. In order to eliminate the risk of these factors and to enhance the comparability between cases, the changes of these price influencing factors are expressed with relative value. Taking 'traffic volume' as an example, its variation range (the rate of increase or decrease) in the *k*th year of its operation period can be calculated as:

$$Q'_k = \frac{\sum_{i=1}^{m} Sim(\bar{Y}, X_i)\, Q_{i,k}}{\sum_{i=1}^{m} Sim(\bar{Y}, X_i)} \tag{12}$$

$$Q_{i,k} = \frac{\bar{Q}_{i,k} - \bar{Q}_{i,k-1}}{\bar{Q}_{i,k-1}} \times 100\% \tag{13}$$

where, m is the number of similar cases; Q'_k is the traffic volume adjustment range of the target case Y; $Sim(\bar{Y}, X_i)$ is the similarity between the selected case X_i and the target case $\bar{Y}$, which will be discussed in the following section; $Q_{i,k}$ is the traffic volume adjustment range of the selected case X_i in the year of k; $\bar{Q}_{i,k}$ and $\bar{Q}_{i,k-1}$ are the traffic volume of the selected case X_i in the year of k and k-1, respectively. Of note, the calculation method also applies to exchange rate, inflation rate, and the following operation cost and price adjustment period (z).

Adjustment coefficient based on project risk

As mentioned above, the influence of some project risks, including force majeure, project quality and service quality on project pricing is included in the operation cost. Moreover, the concession price of PPP projects generally presents a periodic feature (Kumaraswamy and Morris 2002). Accordingly, PPP project price tends to remain stable for a period (e.g. usually 3-5 years) and be adjusted every z years afterwards. That is, the price adjustment range r will adjust the price at the beginning of next period (i.e. every z+1 years). Thus, the periodicity of concession price can be described by Eq. (14).

$$n = \frac{T_C - T - 1}{z} \tag{14}$$

where, $\bar{n}$ is the periodicity of concession price, T_C is the concession period and T is the current research period.

The theoretical price adjustment range of the target case Y is supposed to be same and can be calculated as：

$$r = r_1 = r_2 = \ldots r_n = \frac{\sum_{i=1}^{z} Sim(\bar{Y}, X_i) \mathrm{r}_{i,k}}{\sum_{i=1}^{z} Sim(\bar{Y}, X_i)} \tag{15}$$

$$r_{i,k} = \frac{\bar{r}_{i,k} - \bar{r}_{i,k-1}}{\bar{r}_{i,k-1}} \times 100\% \tag{16}$$

where $r_{i,k}$ is the price adjustment range of the selected case X_i in the year of k; and $\bar{\mathrm{r}}_{i,k}$ and $\bar{r}_{i,k-1}$ is the price of the selected case X_i in the year of k and k-1, respectively.

Combining all the risks identified in Table 1 (i.e. Eq. (9) to Eq. (16)), the actual price adjustment range is calculated as:

$$R_i = r f_1(x)\, f_2(x) f_3(x) \tag{17}$$

where R_i is the actual price adjustment range in the period i.

CBR-based pricing

The CBR-based pricing model consists of: (1) retrieving past similar cases; (2) predicting the value of pricing parameters required in the theoretical pricing model, such as traffic volume (Q_t), exchange rate (e), inflation rate (INF), operation cost (C_t), other revenue (Y_t) in Eq. (8), and the price adjustment mechanism, such as the periodicity of concession price (n) in Eq. (14) and price adjustment range (r) in Eq. (15).

Specifically, using CBR, past similar cases (X_i) are retrieved by comparing their local similarity ($sim_i(a_i^{\bar{Y}}, a_i^{X_i})$) and global similarity ($Sim\ (\bar{Y}, X_i)$) with the new case ($\bar{Y}$). Local similarity (i.e. the attribute similarity score) measures the similarity between the new case's attributes and the local cases in the case database. As shown in Eq. (18), the numerical attribute similarity algorithm is adopted to calculate local similarity for floating attributes.

$$sim_i(a_i^{\bar{Y}}, a_i^{X_i}) = \begin{cases} f_1\left(d\left(a_i^{\bar{Y}}, a_i^{X_i}\right)\right), & a_i^{\bar{Y}} < a_i^{X_i} \\ 1, & a_i^{\bar{Y}} = a_i^{X_i} \\ f_2\left(d\left(a_i^{\bar{Y}}, a_i^{X_i}\right)\right), & a_i^{\bar{Y}} > a_i^{X_i} \end{cases} \tag{18}$$

When $a_i^{\bar{Y}}$ and $a_i^{X_i}$ are string attributes, the string attribute similarity algorithm is used to calculate similarity in Eq. (19).

$$sim_i(a_i^{\bar{Y}}, a_i^{X_i}) = \begin{cases} 1 & (a_i^{\bar{Y}} = a_i^{X_i}) \\ 0 & (a_i^{\bar{Y}} \neq a_i^{X_i}) \end{cases} \tag{19}$$

where, $sim_i(a_i^{\bar{Y}}, a_i^{X_i})$ is the similarity between attributes $a_i^{\bar{Y}}$ and $a_i^{X_i}$; $a_i^{\bar{Y}}$ is the index of the new case, and $a_i^{X_i}$ is the index of the existing case in memory; $d\left(a_i^{\bar{Y}}, a_i^{X_i}\right) = a_i^{X_i} - a_i^{\bar{Y}}$ is the absolute distance between $a_i^{\bar{Y}}$ and $a_i^{X_i}$; $f_1\left(d\left(a_i^{\bar{Y}}, a_i^{X_i}\right)\right)$, $f_2\left(d\left(a_i^{\bar{Y}}, a_i^{X_i}\right)\right)$ is the distance-based similarity function representing the relationships between the distance $d\left(a_i^{\bar{Y}}, a_i^{X_i}\right)$ and the similarity $sim_i(a_i^{\bar{Y}}, a_i^{X_i})$. This similarity function can be computed by MyCBR (version 2.6.6), which is an open-source software developed by School of Computer Science and German Research Centre for Artificial Intelligence (Competence Centre CBR at DFKI, 2020). The value of $sim_i(a_i^{\bar{Y}}, a_i^{X_i})$ is between 0 and 1, where 1 means $a_i^{\bar{Y}}$ and $a_i^{X_i}$ are 100% the same.

Global similarity (i.e. the case similarity score) is then measured by weighing each attribute to show how certain local cases are similar to the new case. Based on the local similarity above, the global similarity is calculated in Eq. (20) and Eq. (21) to identify the most similar case in the case database.

$$Sim(\bar{Y}, X_i) = \sum_{i=1}^{n} w_i \mathrm{sim}_i\left(a_i^{\bar{Y}}, a_i^{X_i}\right) \tag{20}$$

$$w_i = \frac{\sum_{j=1}^{n} x_{\mathrm{ij}}}{M} \tag{21}$$

where $Sim(\bar{Y}, X_i)$ is the global similarity between the new case $\bar{Y}$ and the selected case X_i; w_i is the weight of attribute *i*; *n* is the number of attributes. x_{ij} is the score of indicator *i* in the No. *j* questionnaire; and *M* is the total score of all indicators.

Following the retrieval process in Eqs. (18)-(21), data required for the theoretical pricing model (Eq. (8)) and the price adjustment mechanism (Eq. (17)) can be extracted from the most similar case to formulate the hybrid dynamic pricing model during the residual concession period.

Hybrid Dynamic Pricing model

With the theoretical pricing model and CBR-based pricing model, the hybrid dynamic pricing model is proposed in Eq. (22). The theoretical pricing model provides a basic pricing structure, while the CBR-based pricing model includes the price adjustment mechanism, identifies the most similar past case and provides data input for the theoretical pricing model and the price adjustment mechanism.

$$P_i=P_{i-1}\left(1+R_i\right) \quad (22)$$

where P_i is the price in the residual concession period i, P_{i-1} is the price in period i-1 as shown in Eq. (8), and R_i is the actual price adjustment range in the period i as shown in Eq. (17).

In this hybrid dynamic pricing model, both the traditional pricing parameters and the changing pricing parameters during the residual concession period that impact projects' RV are accommodated. More importantly, the problem of sophisticated residual concession pricing of PPP projects is transformed into the determination of the price adjustment coefficient and prediction of price parameters (Table 2). In doing so, it will not only simplify the settlement of the price adjustment, but also can greatly improve the speed and quality of the pricing process.

Table 2. Input of the model

Category	price adjustment coefficient	price parameters
Input data	$f_1(x)$, $f_2(x)$, $f_3(x)$, Q'_k, r	T_2, P, Q_t, INF_1, INF_2, Y, C_t, A, K_E, R, D, t, C_0

Case Study

Case Background

The WHC project is selected as a case study to test the feasibility of the proposed hybrid dynamic pricing model as it is a good example of transport PPPs that are entering into the residual concession period. The 30-year WHC contract was signed off by Western Harbor Company Limited and former British Hong Kong Government, with the construction period being five years from 1993 to 1997 and the operation period being 25 years from 1997 to 2023. In order to illustrate the process of CBR, the current research time is assumed to be 2012. Hence, the residual concession period is from 2013 to

2023. According to toll shares by vehicle category listed in Table 3, the toll revenue of goods vehicles has been relatively stable, accounting for approximately 14% of all vehicle toll revenue of the WHC. Therefore, the average daily toll of WHC during the remaining operation years (η) can be calculated as:

$$\eta = \overline{A_1} \div 14\% \tag{23}$$

where $\overline{A_1}$ is the average daily toll of goods vehicles.

Table 3. Toll shares for WHC by vehicle category

Vehicle category	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**
Private cars	65%	64%	63%	75%	62%	61%	59%	58%
Goods vehicles	15%	14%	14%	11%	14%	14%	14%	14%
Bus	20%	22%	23%	14%	24%	25%	27%	28%

Source: WHC company annual report (2012)

Additionally, according to the annual reports of WHC, the proportion of the average daily toll of the three types (light, medium, and heavy) of goods vehicles in the last five years is around 7:2:1. Therefore η can be further calculated based on medium goods vehicles as:

$$\eta = \overline{A_1} \div 14\% = (A_1 \div 20\%) \div 14\% = 35 \cdot A_1 \tag{24}$$

where A_1 is the average daily toll of medium goods vehicles. Since the WHC project is approaching the transfer stage, it is imperative that a rational concession price is adjusted to ensure RV in the subsequent management.

Hybrid dynamic pricing of WHC

CBA-based residual concession price of WHC

Reflecting on the WHC case, Eq. (7) can be rewritten as:

$$(1-T_2)\sum_{t=1}^{T-1}[P_t\,Q_t(1+INF_1)+Y-C_t-\mathrm{A}]\frac{1}{(1+K_E)^t}-\mathrm{R}(1-T_2)\sum_{t=1}^{T_\mathrm{F}}(D-\mathrm{At})\frac{1}{(1+K_E)^t}-C_0+(1-T_2)\sum_{t=\mathrm{T}}^{T_n}(Y-C_t-\mathrm{A})\frac{1}{(1+K_E)^t}=-(1-T_2)\sum_{t=\mathrm{T}}^{T_n}[\,Q_t(\mathrm{P}_{2013-2017}+\mathrm{P}_{2018-2023})(1+INF_2)]\frac{1}{(1+K_E)^t} \tag{25}$$

With existing documents on WHC, some data are initially identified:

- As all repayments of WHC have been made in 2012, the interest rate (R) is 2.02% according to WHC company annual report (2012).
- According to the World Bank (2017), annual inflation rate from 1997 to 2012 (INF_1) was calculated to be 5.18%. According to Table 7, annual inflation rate from 2013 to 2023 (INF_2) is 3.68%.
- Income tax rate (T_2) is 16.5% and C_0 is 7 billion HK dollars as stated in Western Harbour Tunnel Company Limited Annual Report 2012 (Company, 2018).
- Internal rate of return (IRR) of the company up to Dec. 2012 generated was 13.4% (Company, 2018).

Therefore, Eq. (25) equates to:

$$0.835\sum_{t=1}^{16}[P_t\,Q_t(1+5.18\%)+Y-C_t-\mathrm{A}]\frac{1}{(1+6.7\%)^t}-0.167\sum_{t=1}^{16}(D-\mathrm{At})\frac{1}{(1+6.7\%)^t}-C_0+0.835\sum_{t=17}^{26}(Y-C_t)\frac{1}{(1+6.7\%)^t}=-1.85\mathrm{P}_{2013-2017}\sum_{t=17}^{26}Q_t\frac{1}{(1+6.7\%)^t} \tag{26}$$

CBR-based pricing model of WHC

Creation of case database

Description of the case problem and solution determines not only how the case will be stored in the database but also how a similar case can be retrieved for resolving the new case. With this in mind, hierarchic organization techniques, which enables rapid access to attributes (Chan et al. 2015), are applied to present cases as PPP projects possess a complex structure comprising different categories (Watson 1999; Ma et al. 2005; Yuan et al. 2018). Therefore, from the perspective of the residual concession price of transport PPPs, the hierarchic case description structure is composed of project basic information, financial information, demand information, price information, risk factors of price, and overall evaluation of projects. As shown in Table 4, 31 attributes have been chosen to represent the PPP project cases and facilitate the retrieval process. A total of 41 projects of tunnel, bridge and highway are collected to create the case database and detailed project background information is listed in Appendix 1.

Table 4. Crucial slots of the pricing-CBR system

Slots	Secondary indicators	Weight	Description	Data type
Category	Category	5.24%	Tunnel、Bridge and Road	String
Starting construction time	Starting construction time	2.06%	Year	Float
Starting operation time	Starting operation time	2.06%	Year	Float
Countries and regions	Legal system	3.23%	0= Anglo-American Law System, 1= Continental Law System	String
	Improvement of PPP-related legislation	3.65%	5=National legislation on PPP projects; 4=Provincial and ministerial legislation or regulations on PPP projects; 3= Only local and municipal regulations; 2=Only County regulations; 1=No relevant legislation or regulations	Float
	Government credit rating	3.55%	Standard Poor's Sovereign credit rating: 9=AAA; 8=AA; 7=A; 6=BBB; 5=BB; 4=B; 3=CCC; 2=CC; 1=C	Float
Concession period	Construction period	3.02%	Year	Float
	Operation period	3.55%	Year	Float
The past operation year	The past operation year	3.55%	Year	Float
PPP type	PPP type	4.29%	BOT、BOOT、DBO、DBFO、TOT、Joint Venture etc.	String
Size	Length	2.49%	km	Float
	Number of lanes	2.17%	Number of two-way Lanes	Float
	Designed	2.91%	Year	Float

	service life			
Financial information	Construction cost	3.55%	Converted to the US dollar in 2010	Float
	Loan amount	2.70%	Converted to the US dollar in 2010	Float
	Lending rates	2.70%	The average value of each interest rate	Float
	Repay deadline	2.81%	Year	Float
	Annual operation cost	3.44%	The average value in the past operation years	Float
	Annual average variation of operating cost	2.81%	Annual average variation in the past operation year, %	Float
	Annual average variation of other income	2.59%	The average value in the past operation years	Float
	Annual average variation of other income	2.28%	Annual average variation in the past operation year, %	Float
	Annual average variation of exchange rate	2.28%	Annual average variation in the past operation year, %	Float
	Annual average variation of inflation rate	2.28%	Annual average variation in the past operation year, %	Float
Demand	Annual average demand	3.55%	Annual average variation in the past operation year	Float
	Annual average variation of	3.12%	Annual average variation in the past operation year	Float

	demand			
Price	Initial price	3.65%	Converted to the US dollar in 2010	Float
	Average adjustment period of price	3.76%	Year	Float
	Average range of price adjustment every time	3.86%	Annual average variation in the past operation year, %	Float
Risk indicators	Government decisions	4.82%	0= Price cannot rise because of government decisions，1=Other situation	String
	Public attitudes	3.86%	0= Price cannot rise because of public attitudes，1=Other situation	String
	Laws and regulations changes	4.18%	0= Price cannot rise because of laws and regulations changes，1=Other situation	String

Case retrieval

Case retrieval (i.e. Pricing-CBR system) is undertaken by using MyCBR (version 2.6.6) and Protégé (version 3.4.8), a knowledge acquisition software. In addition, to accommodate each case's various attributes, the matching process is divided into three steps to generate the best result.

At Step 1, the User Interface (UI) is designed in the 'Forms' tab of Protégé. As shown in Figure 2, a new project named 'PPP Project Cases' is built, with the type and the allowed value assigned to each attribute in the 'Main View'.

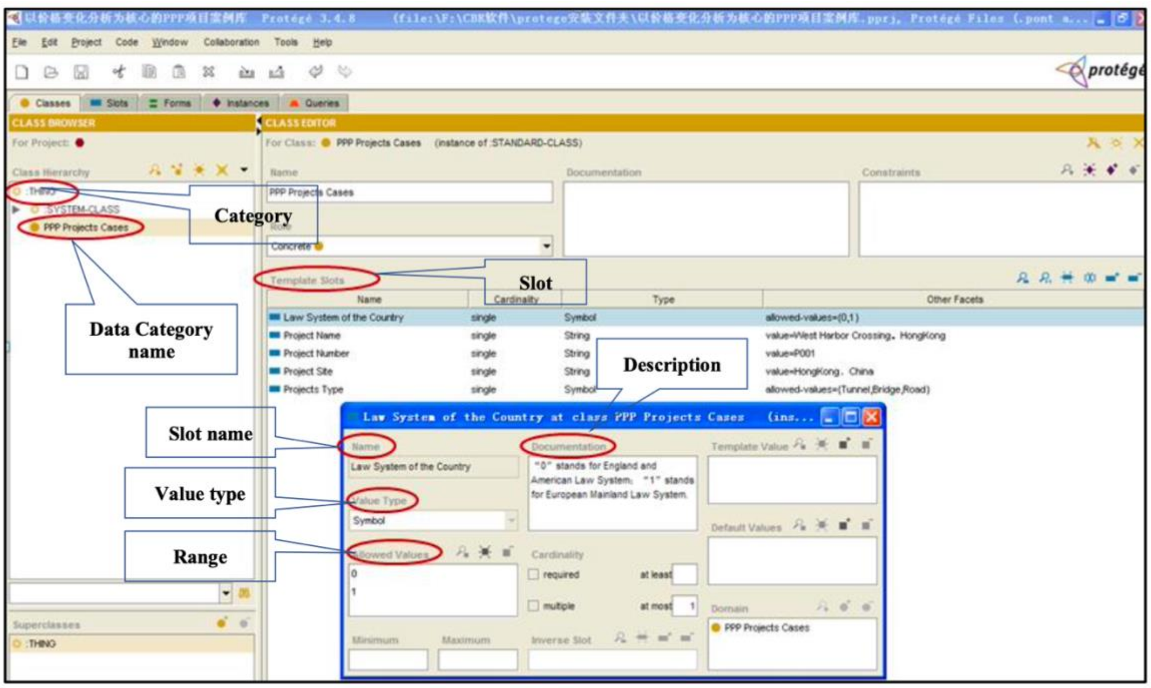

Figure 2. Class and slot setting of PPP project case database

At Step 2, the similar cases whose local similarity is the same as the input problem, and whose global similarity meets the threshold are retrieved. The threshold value is achieved through the adaptive threshold processing, which comprises: (1) setting an initial threshold value ($\bar{G}$) based on experience; (2) constructing two sets of pixels $G1$ and $G2$ ($G1 > \bar{G}$, $G2 \leq \bar{G}$); (3) calculating the average gray value of $G1$ and $G2$, namely $m1$ and $m2$; (4) calculating a new threshold value $\bar{G}'(\bar{G}' = \frac{(m1+m2)}{2})$; and (5) repeating (1)-(4) until the difference between $\bar{G}$values in successive iterations is less than the predefined parameters $\Delta\bar{G}$. Moreover, the weight of each attribute (the third column in Table 4) in the case database is obtained through a questionnaire survey (Appendix 2). 13 experienced experts with 11 experts from academia and two from industry in the field PPPs were surveyed on the importance of indicators on the similarity between two cases field.

At Step 3, the three most similar cases retrieved are EHT, Tate's Cairn Tunnel, and East Yan'an Road Tunnel with the similarity scores being 0.91, 0.87, 0.87, respectively. The most similar case (EHT) is first used as the data input of the theoretical pricing model to set an initial price. Since its similarity score is below 1, all three cases are then selected to calculate the price adjustment mechanism (Eq. (28)). Similar to Liang et al. (2021), the weighted price adjustment range therefore shows the reasonable adjustment process.

Price adjustment mechanism and CBR pricing results

For the adjustment mechanism, as the rise of concession price has not been prevented by government behavior and public attitudes since the operation of WHC, the value of adjustment coefficient of government behavior and public attitude all equals to 1 according to Eqs. (9)-(11).

$$f_1(x) = 1, f_2(x) = 1, f_3(x) = 1 \tag{27}$$

Besides, using Eqs. (12)-(16), the adjustment coefficients of market risks and project risks are calculated in Table 5. As shown in Table 5, the average price adjustment range of EHT, Tate's Cairn Tunnel, and East Yan'an Road Tunnel is 6.19%, 3.89%, 31.66%, respectively. Therefore, the actual price adjustment range (R_i) is calculated using Eq. (17) as:

$$R_i = rf_1\,(\mathrm{x})\,f_2\,(\mathrm{x})f_3\,(\mathrm{x}) = r\times1\times1\times1 = r = \frac{\sum_{i=1}^{z} Sim(\bar{Y},X_i)\mathrm{r}_{i,k}}{\sum_{i=1}^{z} Sim(\bar{Y},X_i)}$$

$$= \frac{0.91\times0.0619+0.87\times0.0389+0.87\times0.3166}{0.91+0.87+0.87} = 0.138 \quad (28)$$

Table 5. The changing features of the pricing parameters of the similar cases

Indicator	Eastern Harbour Tunnel	Tate's Cairn Tunnel	East Yan'an Road Tunnel	WHC
Annual average variation of C_t	-2.14%	3.94%	1.50%	1.05%
Annual average variation of Y_t	-0.05%	-0.04%	-0.11%	-0.07%
Annual average variation of INF_2	0.60%	0.40%	1.50%	0.83%
Annual average variation of Q_t	2.54%	-0.37%	13.94%	5.33%
z	3	8	5	5
r	6.19%	3.89%	31.66%	13.80%
Global similarity	91.00%	87.00%	87.00%	-

In addition, as the average adjustment period of price of WHC is five years (z in Table 5), the periodicity of the residual concession price can be calculated using Eq. (14) as:

$$\bar{n} = \frac{T_C - T - 1}{z} = \frac{2023-2012-1}{5} = 2 \quad (29)$$

That is to say, there are two concession prices during WHC's residual concession period, namely, $P_{2013-2017}$ and $P_{2018-2023}$.

As mentioned above, the most similar past case is EHT (i.e. the similarity score is 0.91). Therefore, it is used to provide data input for the model. The rate of return of EHT in concession year 2004 (T=2004) and concession year 2012 (T=2012) is 9.5% and 13.4%, respectively. By contrast, the rate of return of WHC in concession year 2012 (T=2012) is only 1.05%. Thus, the upper limit of the rate of return of WHC is set as the half of the rate of return of EHT in 2012 ($K_E = 6.7\%$). Furthermore, based on the current research time (2012), other predictive value of pricing parameters of WHC for the residual concession period (from 2013 to 2023) is shown in Table 6, Table 7 and Appendix 3, respectively.

Table 6. The source of data

Parameter	Value	Source
C_t	Table 7	CBR
Y_t		
INF_2		
Q_t		
n		
r		
K_E	6.7%	Calculated based on EHT in 2012
T_2	0.165	
P_t	Appendix 2	WHC annual report
INF_1	5.18%	
Y	Appendix 2	
A	0	
R	0.2	
T_F	16	
D	Appendix 2	

Table 7. The predictive value of pricing parameters from 2013 to 2023

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Operation cost (C_t) (1000 HK dollars)	419683	424095	428552	433057	437609	442208	446856	451553	456299	461096	465942
Other revenue (Y) (1000 HK dollars)	40641	41502	42382	43281	44199	45136	46093	47070	48068	49087	50128
Annual inflation rate (INF_2)	3.53%	3.56%	3.59%	3.62%	3.65%	3.68%	3.71%	3.74%	3.77%	3.80%	3.83%
Daily traffic volume for Medium good vehicles (Q_t)	1429	1505	1586	1670	1759	1853	1951	2055	2165	2280	2401

Hybrid dynamic residual concession price of WHC

Using the price adjustment range in Eq. (28) and the data extracted from EHT, each term in Eq. (26) is analyzed to propose the hybrid dynamic residual concession price of WHC (i.e. $P_{2013-2017}$ and $P_{2018-2023}$):

Part I: $0.835\sum_{t=1}^{16}[P_t\,Q_t(1+5.18\%)+Y-C_t-\mathrm{A}]\frac{1}{(1+6.7\%)^t}$ refers to the present value of after tax profit from 1997 to 2012.

Part II: $0.167\sum_{t=1}^{16}(D-\mathrm{At})\frac{1}{(1+6.7\%)^t}$ refers to the present value of interest after tax from 1997 to 2012.

Part III: $0.835\sum_{t=17}^{26}(Y-C_t)\frac{1}{(1+6.7\%)^t}$ refers to the present value of after tax revenue from 2013 to 2023.

Part IV: $1.85\sum_{t=17}^{26}Q_t\frac{1}{(1+6.7\%)^t}$ refers to the present value of after tax traffic volume from 2013 to 2023.

According to Eq. (8) and the data acquired above, the first residual concession price is calculated as:

$$\mathrm{P}_{2013-2017}=\left|\frac{\text{the present value of net profits over the years from 1997 to 2023}}{\text{the present value of traffic flow from 2013 to 2017}}\right|=|(\textbf{Part}\ \mathrm{I}+\textbf{Part}\ \mathrm{II}+\textbf{Part}\ \mathrm{III})/\textbf{Part}\ \mathrm{IV}|=86\ \text{HK dollars} \quad (30)$$

Using the hybrid dynamic pricing model proposed in Eq. (22), the second residual concession price is calculated as:

$$P_{2018-2023}=P_{2013-2017}\times(1+R_i)=P_{2013-2017}\times(1+13.8\%)=86\times1.138=98\ \text{HK dollars} \quad (31)$$

Discussion

As is revealed by WHC annual report of 2019, the actual concession prices of WHC in 2013 and 2018 are 90 HK dollars and 100 HK dollars, respectively. Both are higher than the predicted price (i.e. 86 HK dollars and 98 HK dollars) and attain a respective error rate of 4.44% and 2%. The lower than 5% error rate suggests that the predicted concession price of the project is reasonable (Barlas 1994) and hence verifies the feasibility and applicability of the proposed model. Notably, the error rate is further reduced (from 4.44% to 2%) when the price adjustment mechanism is employed, indicating that the consideration of dynamic risk factors can reflect the project's changing trend and thus safeguard the RV after transfer. Existing literature also indicates that the closer the actual price and the predicted value is, the more robust and accurate the proposed model is (Yuan et al. 2018). Although the actual prices are higher than the predicted prices, the result is consistent with previous studies on PPPs concession price. A study conducted by Xu et al. (2012) also shows that the predicted value is lower than the actual scenario. Such space not only reserves flexibility in the event of further uncertainties but also provides governments with a reference in terms of how much they can adjust the concession price after transfer. For example, if there is a market fluctuation or public attitudes' change during governments' subsequent management because the concession price is high/ low, governments can reduce/ increase the price within a certain range without sacrificing RV. In addition, as private sectors are profit-driven they tend to set a price (e.g. the actual price) that is higher than the normal price (e.g. the predicted price) to withstand the risks (Chen et al. 2018; Feng et al. 2018). This goes someway to explaining the discrepancy (i.e. error rate 4.44% and 2%) between the actual price and the predicted value.

It should also be noted that many PPPs' concession price when transfer is either too high or too low, leading to the suffer of RV. Different from existing models, this proposed model targets particularly at those PPPs that are in operation and/ or are entering transfer stage. As can be seen, this hybrid dynamic model underpinned by scientific rules is capable of intervening at a certain time (Eq. (14)), calculating the price adjustment range (Eq. (17)), and predicting a reasonable residual concession price (Eq. (22)). Equally important, it addresses the changing attribute of pricing parameters, enabling the dynamic adjustment of this model. In the case of WHC, it assumes that the current research time is 2012. As such, the residual concession prices are $P_{2013`2017}$ and $P_{2018`2023}$. It then calculates the price adjustment range to be 13.8% and predicts the residual concession price to be 86 HK dollars and 98 HK dollars, respectively.

The primary motivation for establishing this model is to achieve the satisfaction trade-off among stakeholders through adjusting the residual concession price. Firstly, theoretical pricing model is calibrated by setting pricing parameters to reasonable values and considering factors of the conditions that create the problem. In practice, the theoretical pricing model based on CBA can be seamlessly used by practitioners (e.g. the private sector) as the CBA method has been widely applied in PPPs to make the investment decision (Penyalver *et al*., 2019). Thus, practitioners can familiarize themselves with the initial model by inputting concession price-related parameters identified above and/ or inputting parameters that are specific to their projects. Then, data from past similar project were extracted by CBR to predict the price of the target case WHC during the residual concession period. It is estimated that the advanced CBR-based hybrid model may create difficulties for practitioners and thus hamper its implementation. Nevertheless, with the facilitation of MyCBR and Protégé, the sophisticated prediction process is simplified and becomes semi-automated. In order to address practitioners' popular refrainment from the 'newborn' (see, for example, Burger and Hawkesworth, 2011 and Chan *et al*., 2019), regular training programs and follow-up workshops can be enacted to enable practitioners' access to professional knowledge and advices and nourish the culture of learning from the 'good'. Although the process can be painful, such initiatives have been proven to be worthwhile over the long term. Examples can be seen in Gann *et al*. (2003) and Liu *et al*. (2018) where bespoken workshops and learning mechanisms widened the adoption of design quality indicators and a life-cycle PPP performance measurement model in the United Kingdom and Australia, respectively. Finally, based on the output of the model, public sectors and private sectors can set and adjust transport PPPs' residual concession price to make informed decisions to satisfy project participants.

For the public sector, utilizing the model output can assist them in initiating governments' pricing policy based on predicted pricing parameters. For instance, policy should aim to minimize the influence of changing risk factors (e.g. public attitudes, market risks and project risks) if the gap between the actual price and theoretical price is large. For the private sector, the model output can be employed to set a concession price that covers the cost of risks they assume in the project. In the meantime, as public attitudes are considered in the price adjustment mechanism, the general public's demand (i.e. an affordable price) can be met, which in turn engenders a stable project revenue. A continuous revenue then serves as the catalyst for accumulating RV for the government after transfer.

Conclusions

PPPs have been adopted worldwide to deliver infrastructure projects and/ or provide public services. As a number of PPPs are entering into the transfer stage, a reasonable concession price during the residual concession period is pivotal for both governments and private sectors. However, due to the changing attribute of pricing parameters, the concession price of transport PPPs is not satisfactory when transferred to the host government. The result is that RV continues to suffer in the post-transfer period. Nevertheless, there is a paucity of rational and systematic concession pricing models of transport PPPs during the residual concession period in the existing literature. To this end, a hybrid dynamic pricing model for transport PPPs has been developed in this study. Specifically, the conventional CBA is adjusted to propose the theoretical pricing model to illustrate the relationships between concession pricing parameters. In order to address the changing price-related risk parameters (i.e. government behavior, public attitude, market risk and project risk), a price adjustment mechanism is then developed using CBR. In addition, by virtue of an historical case database, CBR provides the dynamic hybrid model with required data input for the theoretical pricing model and the price adjustment mechanism. The feasibility of the dynamic hybrid pricing model is validated via the WHC PPP project. Through the employment of CBR, the price-related risk parameters are simulated and the price adjustment range is calculated as 13.8%. Using data acquired from the most similar past case (EHT, similarity score 0.91), the residual concession price is predicted to be 86 HK dollars and 98 HK dollars, respectively.

The contributions of this study are twofold: (1) it highlights that a reasonable concession price beyond the operation period is significant in maintaining RV. This is because a reasonable residual concession price can be set through the hybrid dynamic model, which will guarantee the project profitability after the transfer stage and further secure its RV; and (2) it provides a dynamic hybrid pricing model for governments and private sectors to calibrate the current less-than-satisfactory residual concession price. This is because it is tested to be able to adjust, correct and track the residual concession price of transport PPPs, especially highways. Future research can be conducted to expand this model to a wider sector and empirically examine the impact of a reasonable residual concession price on the accumulation of RV.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

The authors would like to express their appreciation for the reviewers' constructive and insightful comments and suggestions. The authors would also like to thank the Scientific Research Foundation of Nanjing Institute of Technology (YKJ201986) and National Natural Science Foundation of China (NSFC 71671042) for financial support. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Natural Science Foundation and the Scientific Research Foundation of Nanjing Institute of Technology.

Notation

The following symbols are used in this paper:

$B_t - C_t$= net profit in year *t*

P_t = the concession price in year *t*

Q_t= the traffic volume in year *t*

Y_t= the other revenue in year *t*

T_1= the sales tax rate

C_t= the operation cost in year *t*

e_t= the exchange rate in year *t*

e = the exchange rate in every year

R_t= the interest in year *t*

R = the interest in every year

D_t= the loan in year *t*

C_d= the depreciation

T_2 = the income tax rate

A = the annual principal repayment

P = the initial price

INF= the annual rate of inflation

INF_1 = the average inflation rate in the past operation period

INF_2 = the average inflation rate in the residual concession period

T_c = the concession period (i.e. unit: year)

T_0 = the construction period (i.e. unit: year)

C_0 = the total investment

T_F = the payment deadline agreed in the contract

T = the operation period at current research time

K_E= discount rate

m =the number of similar cases

Q_k'= the traffic volume adjustment range of the target case $\bar{Y}$

$Q_{i,k}$ = the traffic volume adjustment range of the selected case X_i in the year of *k*;

$\bar{Q}_{i,k}$ =the traffic volume of the selected case X_i in the year of *k*

$\bar{Q}_{i,k-1}$ is the traffic volume of the selected case X_i in the year of *k-1*

$r_{i,k}$=the price adjustment range of the selected case X_i in the year of *k*

$\bar{r}_{i,k}$ and $\bar{r}_{i,k-1}$ = the price of the selected case X_i in the year of *k* and *k-1*

R_i = the actual price adjustment range in the period *i*

$\mathrm{Sim}(\bar{Y}, X_i)$ = the similarity between the selected case X_i and the target case $\bar{Y}$

$sim_i(a_i{}^{\bar{Y}}, a_i{}^{X_i})$ = the similarity between attributes $a_i{}^{\bar{Y}}$ and $a_i{}^{X_i}$

$a_i{}^{\bar{Y}}$ =the index of the new case

$a_i{}^{X_i}$=the index of the existing case in memory

$d(a_i{}^{\bar{Y}}, a_i{}^{X_i})$ =the absolute distance between $a_i{}^{\bar{Y}}$ and $a_i{}^{X_i}$

$f_1\left(d(a_i{}^{\bar{Y}}, a_i{}^{X_i})\right)$, $f_2\left(d(a_i{}^{\bar{Y}}, a_i{}^{X_i})\right)$ = the distance-based similarity function

w_i = the weight of attribute *i*

n = the number of attributes

x_{ij} is the score of indicator i in the No. j questionnaire

M is the total score of all indicators

P_i = the price in the residual concession period i

P_{i-1} = the price in period i-1

$\bar{n}$ =the periodicity of concession price

η=the average daily toll of WHC during the remaining operation years

$\overline{A_1}$ = the average daily toll of goods vehicles

A_1 is the average daily toll of medium goods vehicles

$\bar{G}$ =setting an initial threshold value

$G1$ and $G2$= two sets of pixels

$m1$ and $m2$= the average gray value of $G1$ and $G2$

$\bar{G}'$ =a new threshold value ($\bar{G}' = \frac{(m1+m2)}{2}$)

$\Delta\bar{G}$=the predefined parameters

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